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February 23, 2005

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FILING DATE: *January 22, 2004*
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PATENT

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COVER SHEET FOR FILING PROVISIONAL APPLICATION
(37 CFR §1.51(c)(1))

I hereby certify that this correspondence is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 addressed to Mail Stop Provisional Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on January 22, 2004 under "EXPRESS MAIL" mailing label number EL 99443 5309US.

Janet M. Stevens

Janet M. Stevens

Mail Stop Provisional Patent Application
Commissioner for Patents
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Alexandria, VA 22313-1450

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR §1.53(c).

1. **The name(s) of the inventor(s) is/are:**

Inventor 1: Oleg V. Sulima
Address: 58 Shull Drive, Newark, DE 19711

2. **The title of the invention is:**

HIGH-SPEED DOUBLE-HETEROSTRUCTURE AlGaAsSb PHOTODETECTORS SENSITIVE IN A 1.3 – 1.55 μm WAVELENGTH RANGE AND PHOTOTRANSISTORS SENSITIVE AT WAVELENGTHS > 2 μm

3. **The correspondence address for this application is:** Customer No. 025191.

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4. **Identification of documents accompanying this cover sheet:**

A. **Documents required for filing date under 37 CFR §§ 1.51(c)(2)-(3) are:**

8 Page(s) of Specification and Drawings

B. **Additional Documents:**

[x] A Patent Application Bibliographic Data Sheet
[ ] A combined Declaration and Power of Attorney
[ ] Assignment
[ ] Other

5. Small Entity Status

The filing fee for this provisional application, as set in 37 CFR §1.16(k), is $160.00, for other than a small entity, and $80.00, for a small entity. See 37 CFR §1.27.

[ ] Applicant is a small entity.
[✗]Applicant is not a small entity.

6. Method of Payment of Filing Fee for this Provisional Application for Patent

[x] A check in the amount of $160.00 is enclosed.
[x] The Commissioner is hereby authorized to charge Deposit Account 50-1446 for any fee deficiency.

Respectfully submitted,

January 22, 2004
Date

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Title: High-speed double-heterostructure AlGaAsSb photodetectors sensitive in a 1.3 – 1.55 μm wavelength range

Inventor(s): __**Oleg_V. Sulima**_____

Brief Summary: A high-speed photodetector operating at room temperature in a 1.3 – 1.55 μm wavelength range consists of a narrow bandgap low doped (ν or π) AlGa(As)Sb absorption layer (E_{g1} = 0.72 - 0.78 eV) having heterojunctions from both sides with wider bandgap AlGaAsSb layers ($E_{g2} \geq E_{g1} + 3kT$), where k is the Boltzmann constant and T is temperature in Kelvin. One of the heterojunctions serves as a p-ν or n-π junction while the other is an ν-n or π-p type junction between the absorption and passivation layers. Such a design provides absorption of the 1.3 – 1.55 μm light only in the absorption layer, which can be totally depleted by applying a reverse bias to the ν-n or π-p junction. The first 10 GHz AlGaAsSb photodetectors with the above design operating at room temperature at 1.55 μm wavelength are demonstrated.

Basic Idea: The proposed design allows confining the light absorption depth by placing the narrow bandgap absorption layer between two wide bandgap lattice-matched layers. In particular, for a 1.3 – 1.55 μm wavelength application, a narrow bandgap low doped (ν or π) AlGa(As)Sb absorbing layer ($Eg \approx$ 0.72-0.78 eV) has heterojunctions from both sides with higher bandgap AlGaAsSb layers (i.e. Eg = 0.85 eV). One of the heterojunctions serves as a p-ν or n-π junction while the other is an ν-n or π-p type junction between the absorption and passivation layers. Such a design provides absorption of the 1.3 – 1.55 μm light only in the absorption layer, which can be totally depleted by applying a reverse bias to the p-ν or n-π junction. Because of that only a fast drift and not a slow diffusion of photogenerated carriers takes place in the device resulting in a high-speed operation. By changing the thickness of the absorption layer one can vary the drift time of the photogenerated carriers and thus control the speed of the photoresponse.

The proposed photodetector can operate both as a p-i-n diode and avalanche photodiode – APD (Fig.1), or - by shifting the p-ν or n-π junction into one of the wide bandgap layers – as an APD with separate absorption and multiplication – SAM APD (Fig.2).

Structural Elements: See the attached drawing.

Problem to be Solved:

Although AlGaAsSb/GaSb- based heterostructures have a large potential for application in near infrared photodiodes for telecom, free-space optical communication, imaging and spectroscopy, they were studied and realized essentially less than InGaAs/InP structures. A uniquely high ratio of the hole ionization coefficient β to the electron ionization coefficient α both in AlGa(As)Sb (up to 60 in $Al_{0.4}Ga_{0.96}Sb$ at room temperature) may allow minimization of noise in AlGa(As)Sb photodiodes with internal gain - APDs or SAM-APDs. Thus, one can expect superior characteristics of AlGa(As)Sb/GaSb APDs and SAM-APDs in comparison with InGaAs/InP counterparts. For the most applications, the photodetectors (p-i-n, APDs or SAM-APDs) must be fast. High-speed (about 10 GHz) operation of AlGaSb avalanche photodiodes with a gain-bandwidth product of 90 GHz at 1.3 μm has been already demonstrated. However realization of AlGaAsSb photodiodes for high-speed operation around 10 GHz at 1.55 μm has not been shown yet. The proposed design of the photodetector with a low bandgap absorption layer neighboring two wide bandgap layers can provide the necessary speed. The first 10 GHz p-i-n AlGaAsSb photodetectors with the proposed design operating at room temperature at 1.55 μm wavelength are demonstrated (see Fig.A1 in Appendix 1).

Advantages

Among different possible applications, it is worth mentioning the following:

(i) photodiodes for telecommunications,
(ii) free-space optical communication,
(iii) imaging and spectroscopy

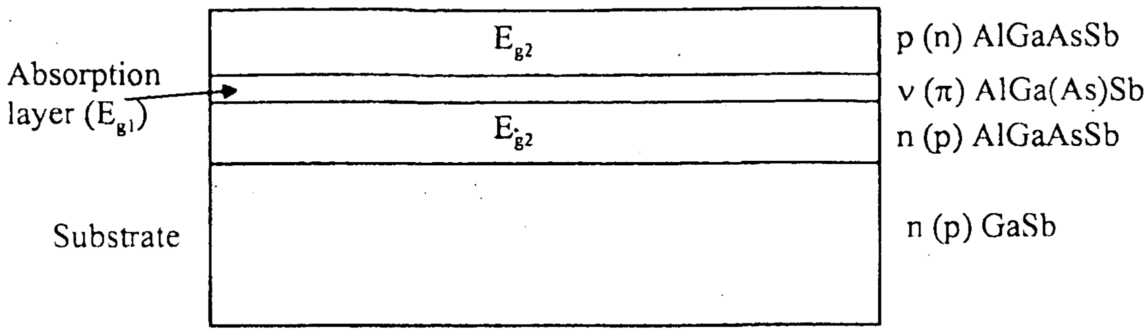

Figure 1. Scheme of the proposed high-speed AlGaAsSb /AlGaSb/GaSb p-i-n or avalanche photodiode. $E_{g2} \geq E_{g1} + 3kT$. The photodiode can be illuminated from either side.

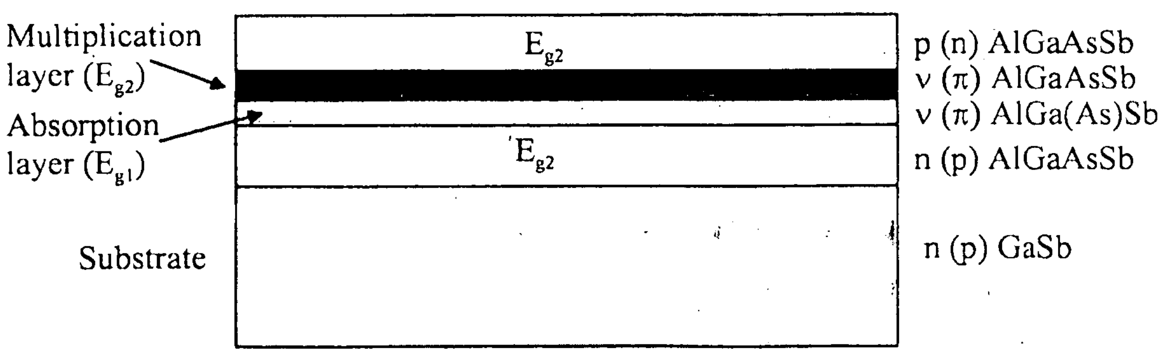

Figure 2. Scheme of the proposed high-speed AlGaAsSb /AlGaSb/GaSb avalanche photodiode with separate absorption and multiplication layers. $E_{g2} \geq E_{g1} + 3kT$. The SAM-APD can be illuminated from either side.

Appendix I

Results of measurements of $Al_{0.4}Ga_{0.6}As_{0.04}Sb_{0.96}$ /$Al_{0.03}Ga_{0.97}Sb$/ $Al_{0.4}Ga_{0.6}As_{0.04}Sb_{0.96}$/GaSb p-i-n photodiodes performed at the University of Delaware

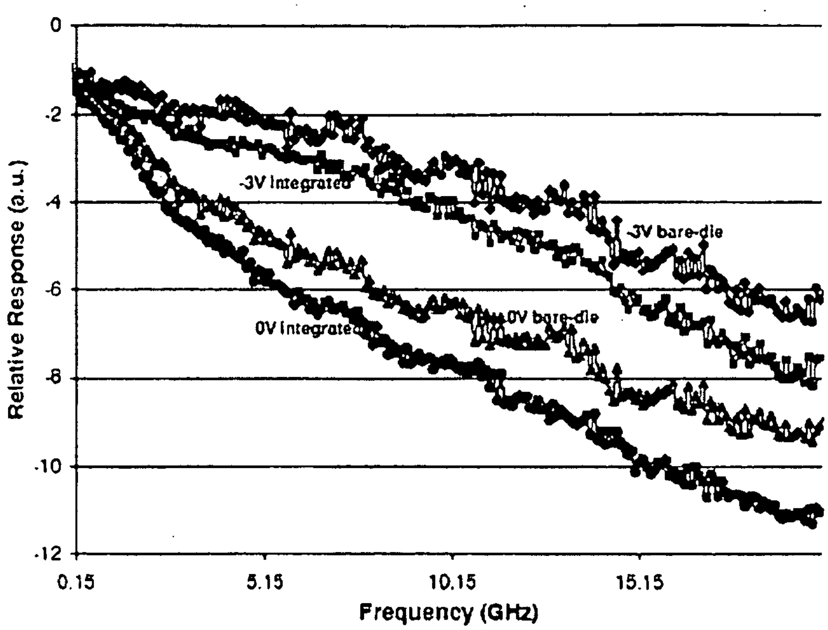

Figure A1. Frequency response of bare-die and polymer flip chip (P_FC) integrated $Al_{0.4}Ga_{0.6}As_{0.04}Sb_{0.96}$ /$Al_{0.03}Ga_{0.97}Sb$/ $Al_{0.4}Ga_{0.6}As_{0.04}Sb_{0.96}$ /GaSb p-i-n photodiode fabricated at AstroPower and University of Delaware and measured at room temperature, at different reverse bias, and at a wavelength of 1.55 μm. The roll-off point of all these curves is at around 10 GHz.

Title: Phototransistors sensitive at wavelengths > 2 μm

Inventor(s): __Oleg_V. Sulima_____

Brief Summary: First phototransistors operating at wavelengths > 2 μm are demonstrated. The phototransistor consists of a wide bandgap n-type emitter (AlGaAsSb with a bandgap *Eg* about 1 eV), composite p-type base (AlGaAsSb with *Eg* about 1 eV and InGaAsSb with *Eg* about 0.55 eV), and n-type narrow bandgap collector (InGaAsSb with *Eg* about 0.55 eV). This device has two p-n junctions - in a wide and narrow bandgap layers - and operates as a phototransistor, when illuminated through the wide bandgap forward biased emitter.

Basic Idea: Radiation with the wavelength >2 μm incident on the wide bandgap n-type AlGaAsSb emitter passes through it unattenuated and is absorbed in the InGaAsSb part of the p-type AlGaAsSb/InGaAsSb composite base, base-collector depletion region, and n-type InGaAsSb collector. The holes photogenerated in the narrow bandgap part of the base or swept into it from the collector increase the forward bias of the base-emitter junction, which causes a large electron current to flow from emitter to collector. The P-p band discontinuity in the composite base prevents holes from injection to the emitter, while electrons from the emitter inject freely (Fig. 1).

Structural Elements: See the attached drawing.

Problem to be Solved:

There is a strong necessity for photodetectors sensitive at wavelengths > 2 μm and exhibiting internal gain. Two semiconductor material systems, which can fulfill the above requirements, are InGaAs-on-InP and InGaAsSb-on-GaSb. Growth of InGaAs is studied relatively well, however to reach sensitivity at wavelengths > 2 μm, so called extended wavelength InGaAs photodetectors are necessary. Strained InGaAs layers (not lattice matched to InP substrates) are applied in these devices, which may result in inferior crystal quality of photoactive layers and hence moderate device parameters. This explains the lack of InGaAs-based devices sensitive at wavelength > 2 μm exhibiting internal gain. In contrast to InGaAs, InGaAsSb layers with the bandgap corresponding to 2 μm, can be grown lattice matched to GaSb substrates. Lattice match of these layers can provide their high crystal quality and make the InGaAsSb-on-GaSb system the best choice for devices with internal gain.

There are three types of semiconductor devices, which can provide the internal gain: (i) avalanche photodiodes (APD), avalanche photodiodes with separate absorption and multiplication layers (SAM-APD), and phototransistors. Several groups in USA, Russia and France have demonstrated a possibility of fabrication of InGaAsSb-based APDs and SAM-APDs. However, fabrication of APDs and SAM-APDs is related with obvious difficulties caused by necessity of operating at elevated voltages and having low-doped and very homogenous material. Without providing these properties, avalanching either does not start or proceeds locally, what may cause generation of micro-plasma and damage of the devices. Moreover, APDs and SAM-APDs are very sensitive to applied voltage and operating temperature. Thus, complicated systems of voltage/temperature stabilization might be necessary for their efficient operation.

Phototransistors (PHT) are not so sensitive to voltage/temperature and can operate at much lower voltages (only several volts). Nevertheless, there are no publications regarding phototransistors sensitive at wavelengths > 2 μm. The lack of these devices may be caused by several reasons. First of all, n-p-n InGaAsSb-based PHT requires a wide bandgap window (lattice matched AlGaAsSb) for a surface passivation. Otherwise, due to large absorption coefficients in InGaAsSb and due to a high surface recombination typical for this material, the carriers are generated near the InGaAsSb emitter surface where they quickly recombine. On the other hand, when an n-type wide bandgap AlGaAsSb is used, the zone diagram of n-AlGaAsSb/p-InGaAsSb is not favorable for the phototransistor operation. In particular, the bandgap discontinuity between n-AlGaAsSb and p-InGaAsSb appears mostly as a barrier in the conduction band, which prevents the electron injection from a forward biased n-AlGaAsSb emitter (Fig.2). To solve this fundamental problem, a composite base consisting of a p-AlGaAsSb and p-InGaAsSb can be suggested (Fig.1). In this case, no band discontinuities exist between the emitter and the base, and the injection from the forward biased emitter occurs freely. At the same time, the P-p valence band discontinuity prevents holes from injection to the emitter. Thus, the emitter-base injection efficiency of this structure is high.

The suggested design (Fig.1) is very flexible and it can be optimized for certain applications. For example, a high optical gain but relatively low-speed operation can be achieved with low-doped collector and base layers. In contrary, to increase the speed of the PHT, the capacitance of the collector-base junction should be low, what can be achieved through a high doping of the InGaAsSb part of the base. Also, a higher speed of the PHT can be expected in a design using a collector with the bandgap wider than that of the base. Furthermore, thickness of the base layer is a definite issue for finding a trade-off between the optical gain and speed.

Advantages

Among different possible applications, it is worth mentioning the following:

(i) Light Detection and Ranging – LIDAR
(ii) Atmospheric studies (CO_2 profiling, monitoring of pollutants)
(iii) Medicine (noninvasive blood glucose monitoring)

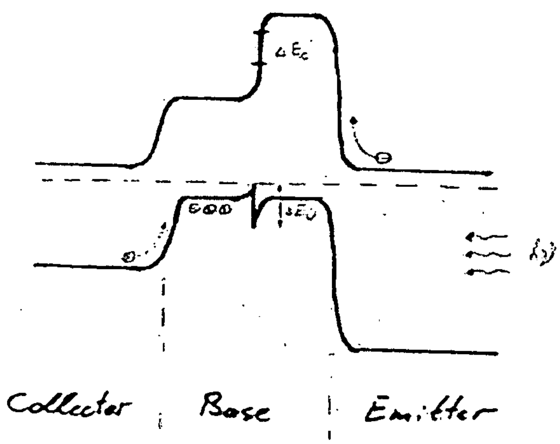

Fig.1 Energy-band diagram of the proposed AlGaAsSb/InGaAsSb phototransistor structure with a composite AlGaAsSb/InGaAsSb base

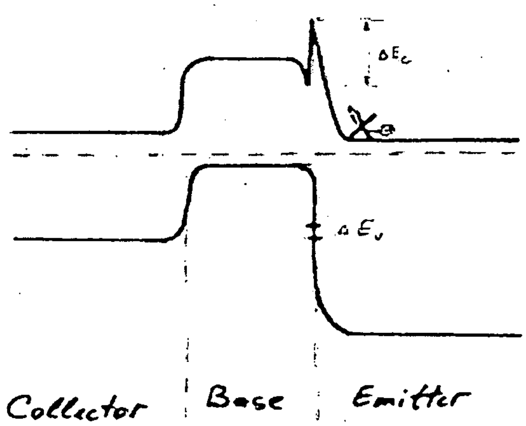

Fig.2 Energy-band diagram of the AlGaAsSb/InGaAsSb phototransistor structure with an InGaAsSb base

Appendix I

Results of measurements of AlGaAsSb/InGaAsSb phototransistors performed at NASA Langley Research Center

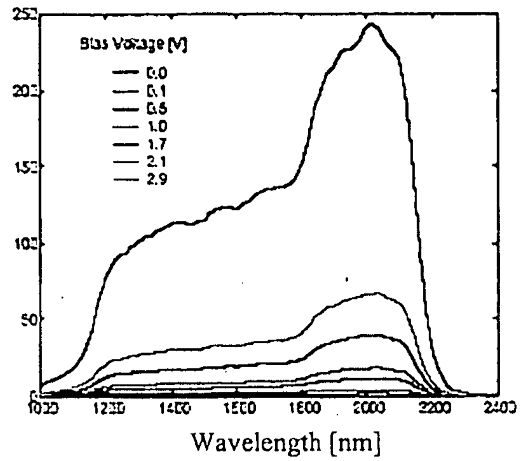

Fig. A1. Spectral response (in A/W) of an AlGaAsSb/InGaAsSb phototransistor at different applied biases measured at 20°C

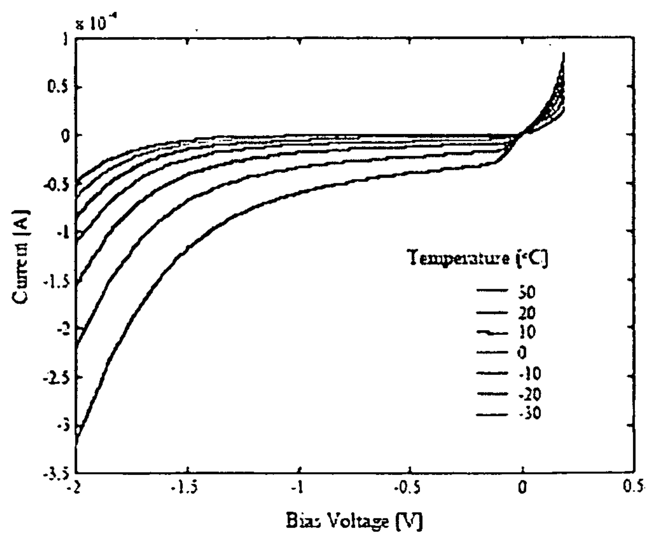

Fig. A2. I-V characteristics of an AlGaAsSb/InGaAsSb phototransistor at different temperatures

Application Data Sheet

APPLICATION INFORMATION

Application Type::	Provisional
Subject Matter::	Utility
Title::	HIGH-SPEED DOUBLE-HETEROSTRUCTURE AlGaAsSb PHOTODETECTORS SENSITIVE IN A 1.3 – 1.55 μm WAVELENGTH RANGE AND PHOTOTRANSISTORS SENSITIVE AT WAVELENGTHS > 2 μm
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Request for Non-Publication?::	No
Small Entity::	No
Petition included?::	No
Secrecy Order in Parent Appl.?::	No

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